

Small Lunar Rovers

Moon Express Workshop



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Lunar Rovers \neq Terrestrial Rovers

Radiation tolerant electronics

- TID (total ionizing dose) may be limited for short mission

Thermal constraints

- Worse than orbit due to regolith and shading

Power constraints

- Solar only

Communications constraints

- Bandwidth, latency, availability, antenna size and pointing

Mass constraints

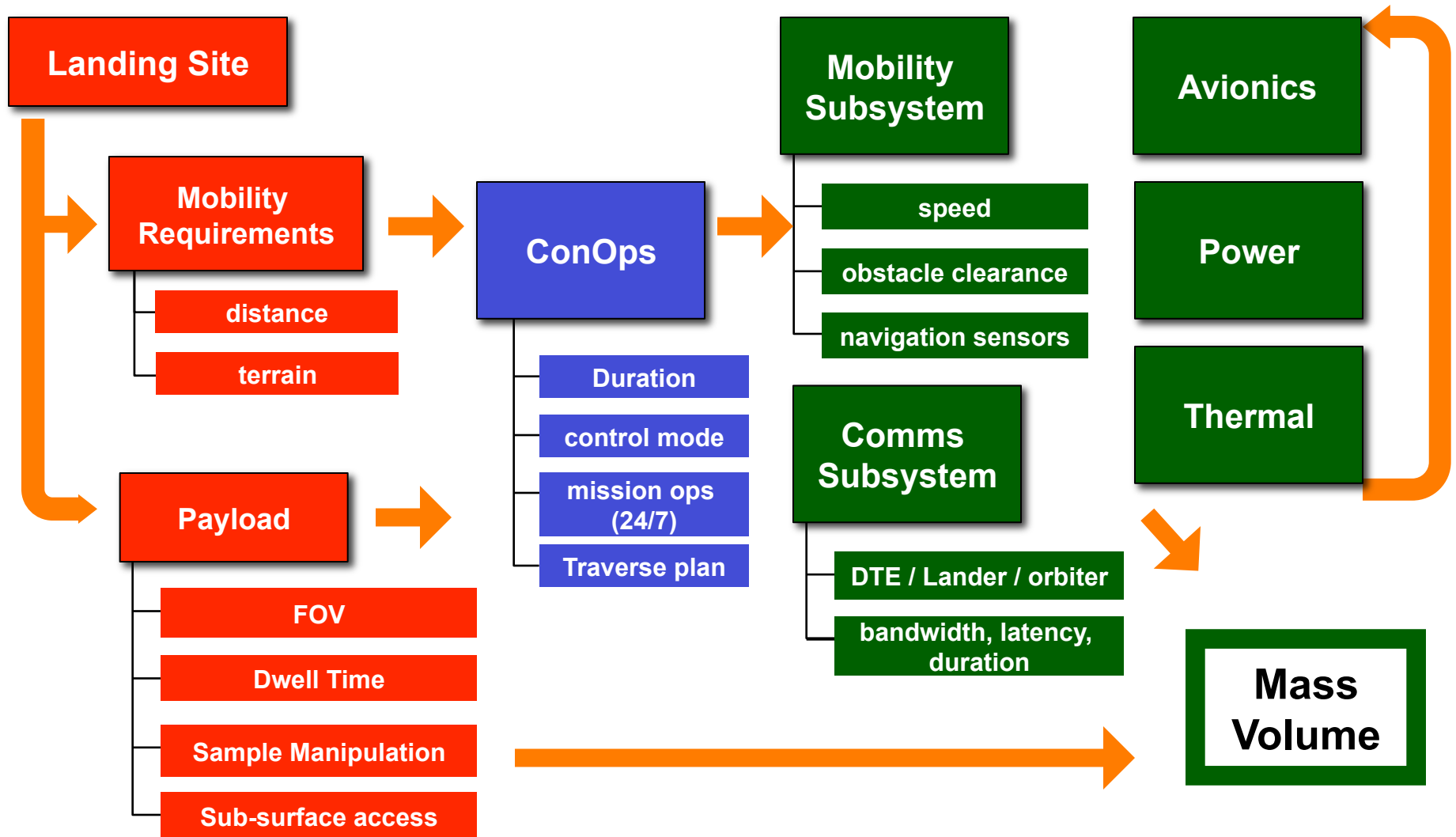
- 8-16% payload mass fraction for planetary rovers (Sojourner, MER)
- Ex. 1 kg payload implies a 10 kg rover (to first order)

Ops constraints

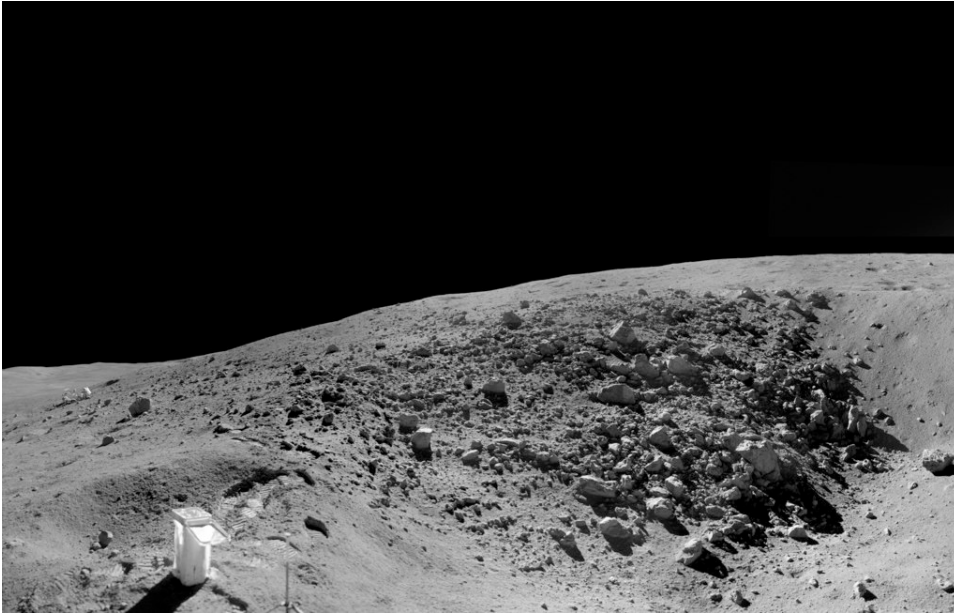
- Lander egress
- Potentially high-tempo operations (if not able to survive lunar night)



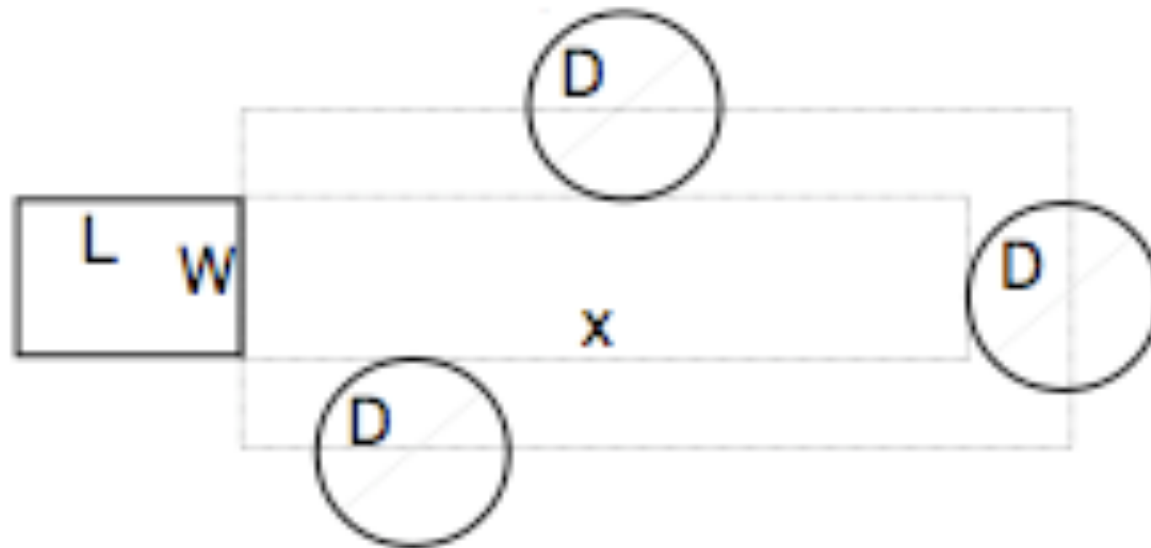
Rover Design Space



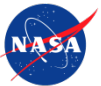
Mobility Hazards



Mean Free Path (x) Computation

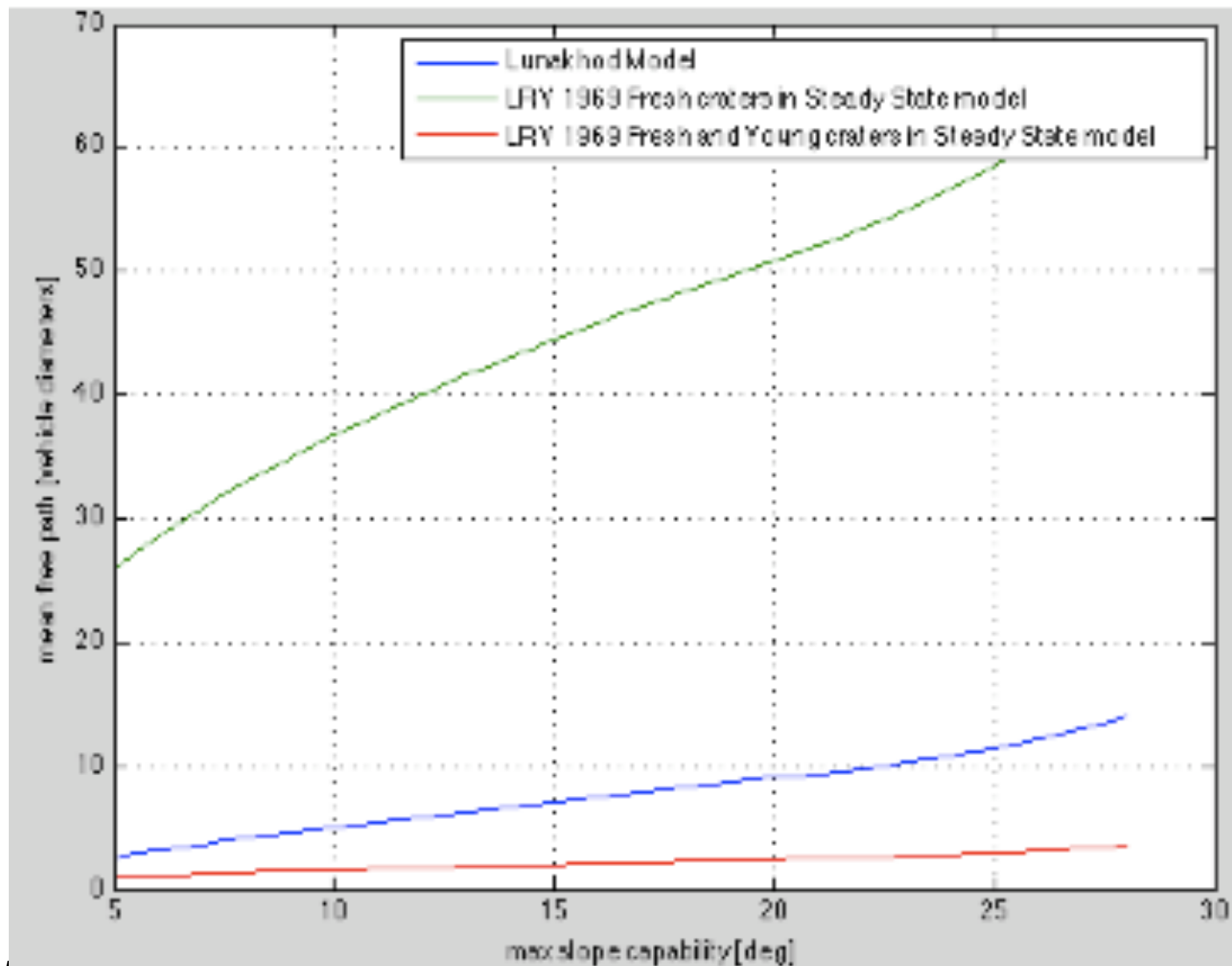


$$\int_{D_0}^{\infty} (x + D/2)(W + D)\rho(D)dD = 1$$



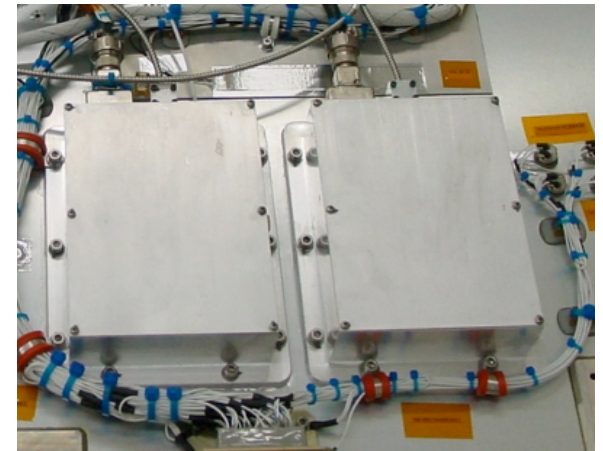
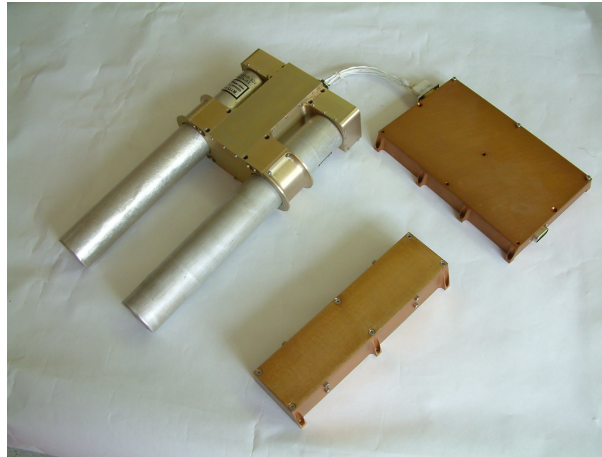
Mean Free Path

Rover body lengths before contacting a non-traversable crater

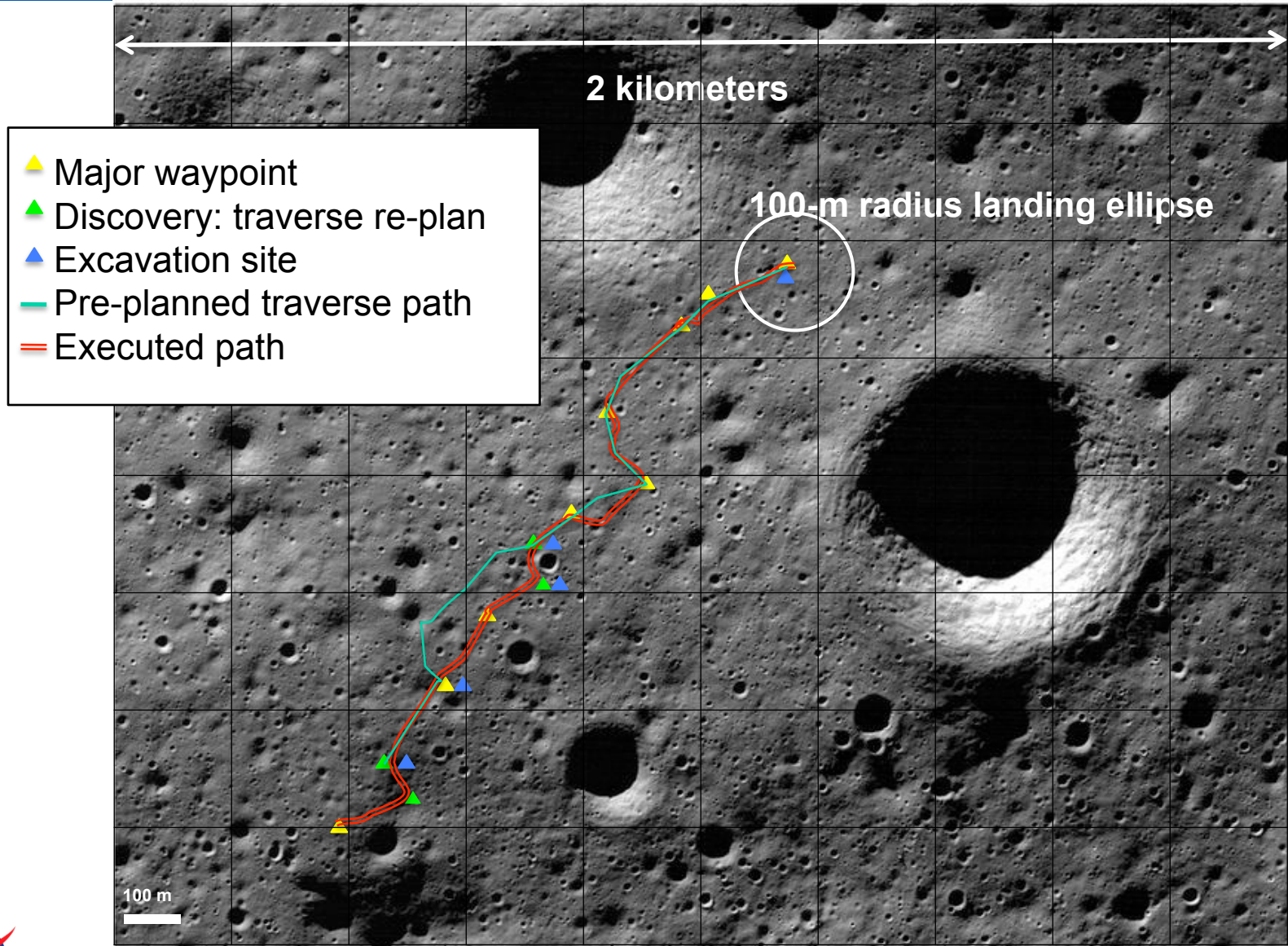


Notional Payload for Prospecting (Polar Volatiles)

Instrument	Principle Measurement	Mass (kg)	Power (W)	Dimensions (cm)	Data Rate (bytes/sec)
Neutron Spectrometer	Hydrogen at depth (to 1 wt% water @ 100 cm)	<1.5*	2	18 x 12 x 6	89
NIR Spectrometer	Volatiles & ice state (1.3 to 2.9 μm)	2	4	10 x 10 x 3	540
Pneumatic Excavator	Subsurface access (5 to 20 cm depth)	2	<5	<i>tbd</i>	<100



Notional Traverse Plan for Prospecting



ConOps: Driving

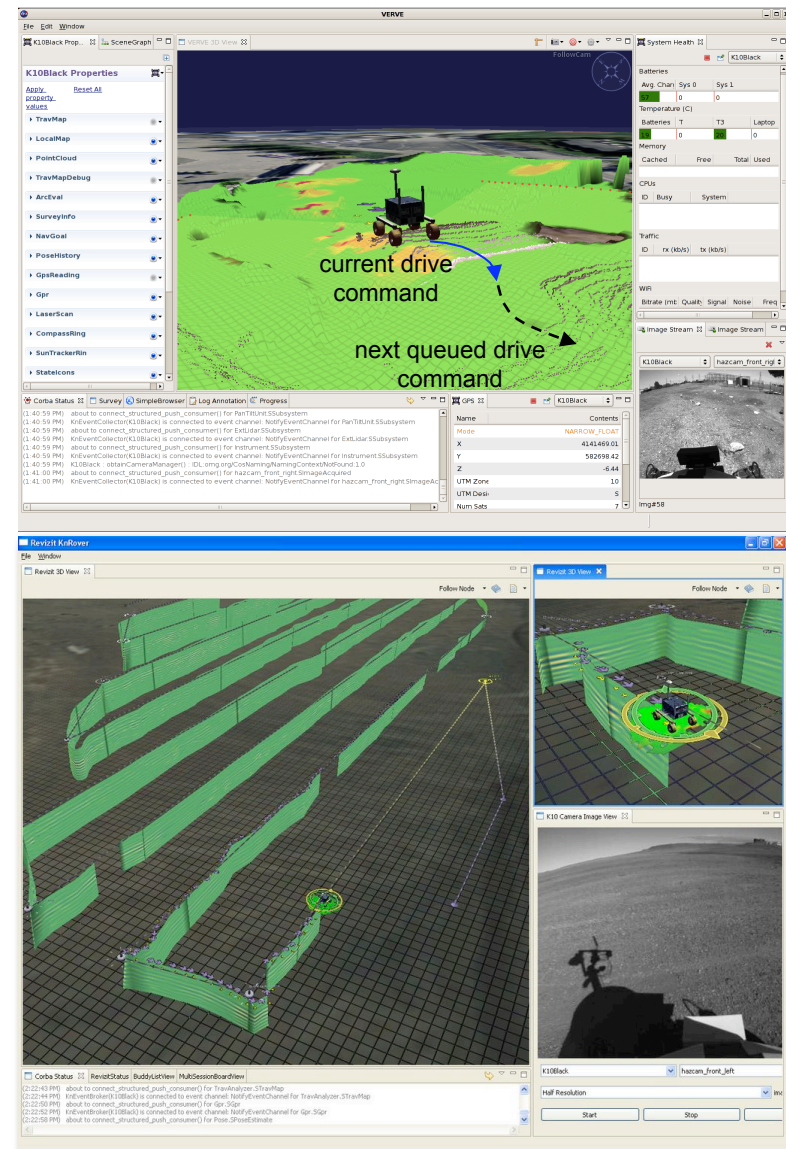
Near Real-Time Tele-Operation

- Navigation data (images, 3D scans) acquired every 1m,
- MOC specifies next immediate drive commands based on prior navigation images (if sufficient coverage)
 - Mapping and drive command generation may be done automatically off-board
- Rover executes next drive command, pausing until all queued navigation images (and related navigation data) downloaded.

If no drive commands available, rover stops and waits further instructions

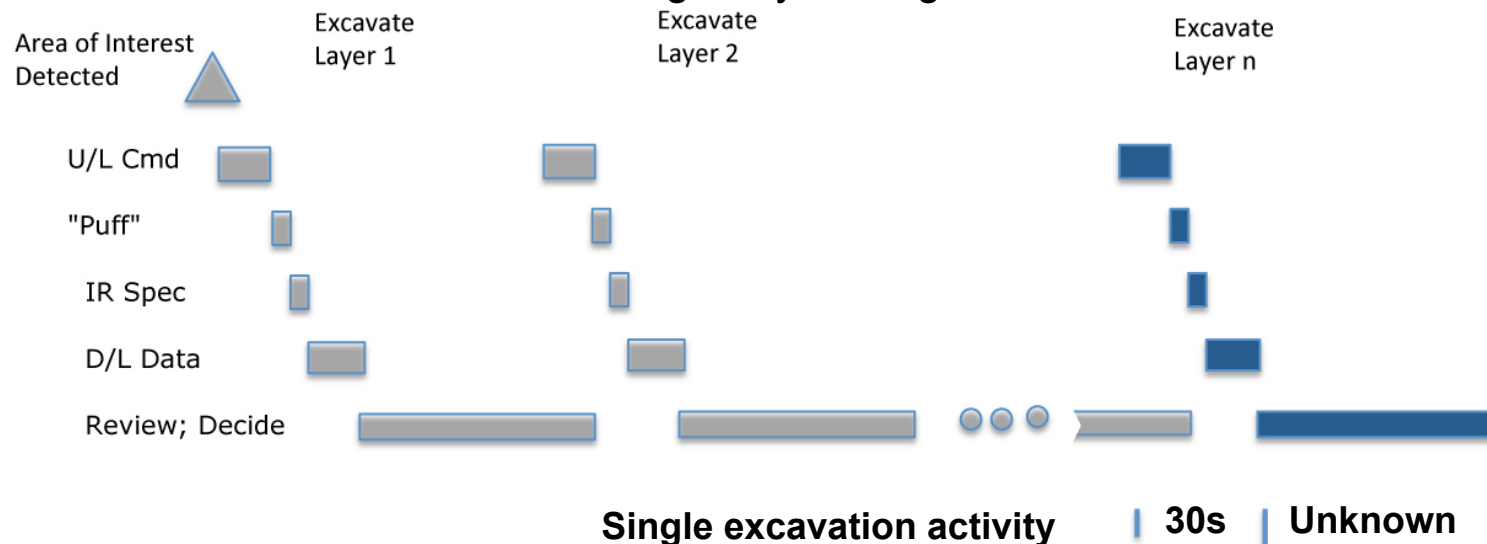
Autonomous Navigation

- Recover from loss of communications (e.g. drive back to last good comm location).
- Intentionally traverse no comm zone

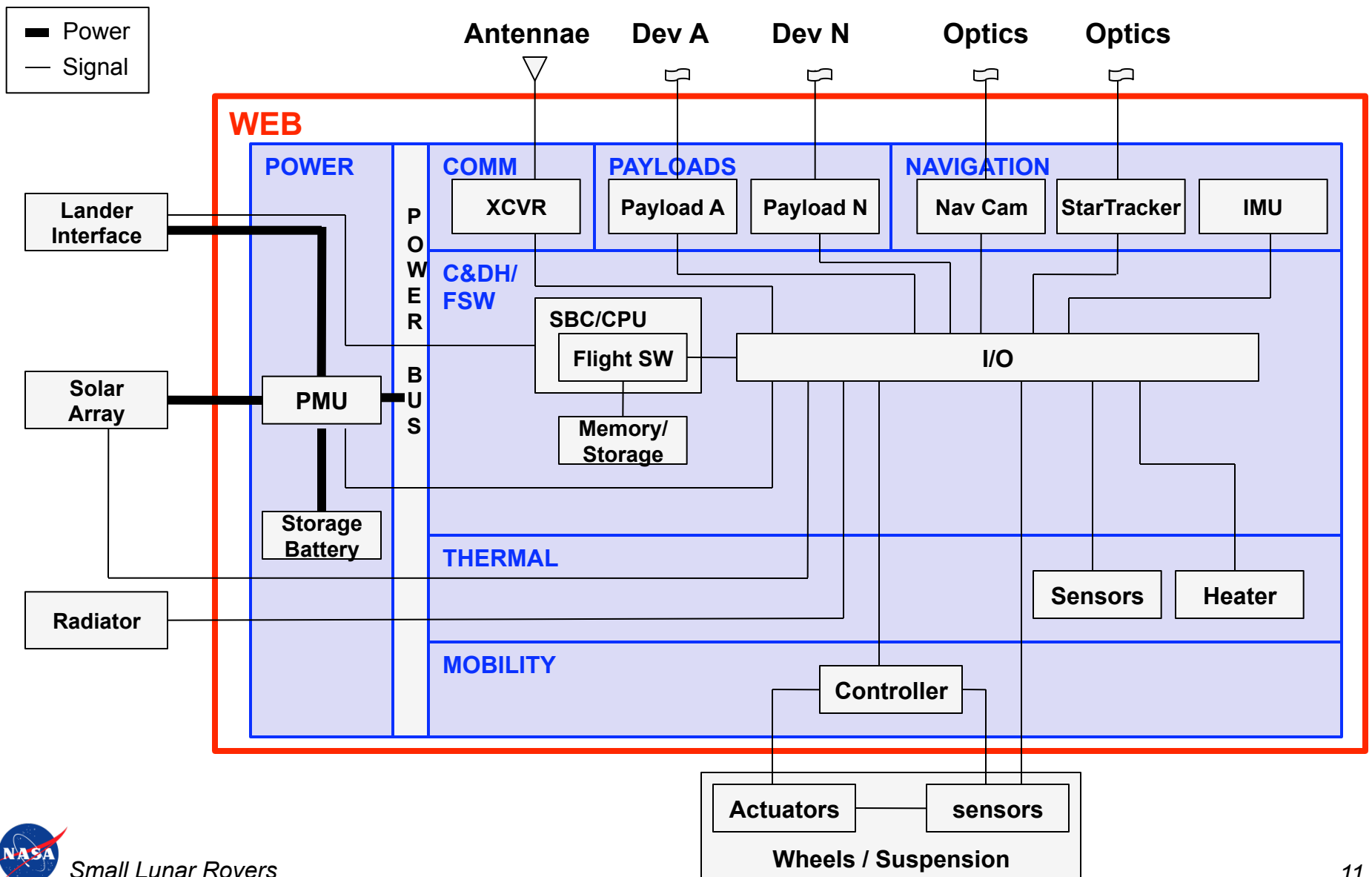


ConOps: Excavation

- Command uplink, excavation, stereo image and NIR spec acquisition and downlink approx 30 sec.
- MOC reviews data and makes decision on whether to excavate additional layer.
- Repeat until either target depth achieved (0.2 – 0.5m), “frost line” achieved, or MOC decides to move on to next target.
- Assuming 5 excavation layers and 10 mins review time for each, the complete excavation activity takes approx 1 hour, or 10 hours for 10 excavations.
- Data review and decision making likely limiting factor.



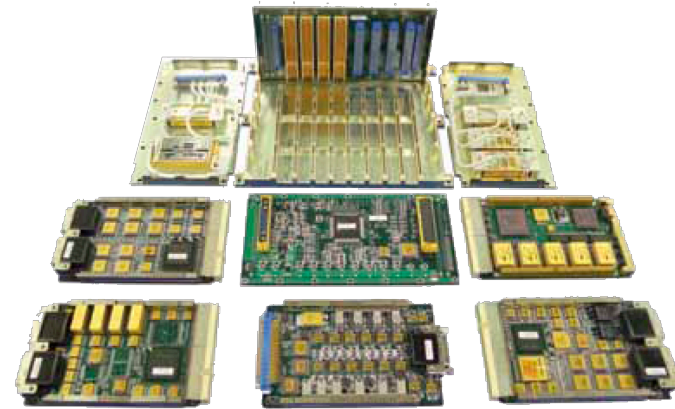
Functional Block Diagram



Avionics

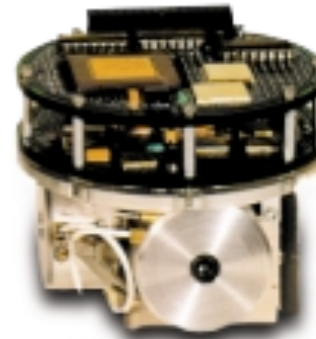
Typical Integrated Avionics Package

- < 5kg, < 32W@28V
- 266 MIPS/266 MFLOPS CPU
- 16MB NVRAM, 512MB SDRAM, 512MB DDR RAM
- RS 422, LVDS, & 1553 IO, Power switches, analog and solar array inputs



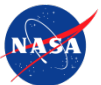
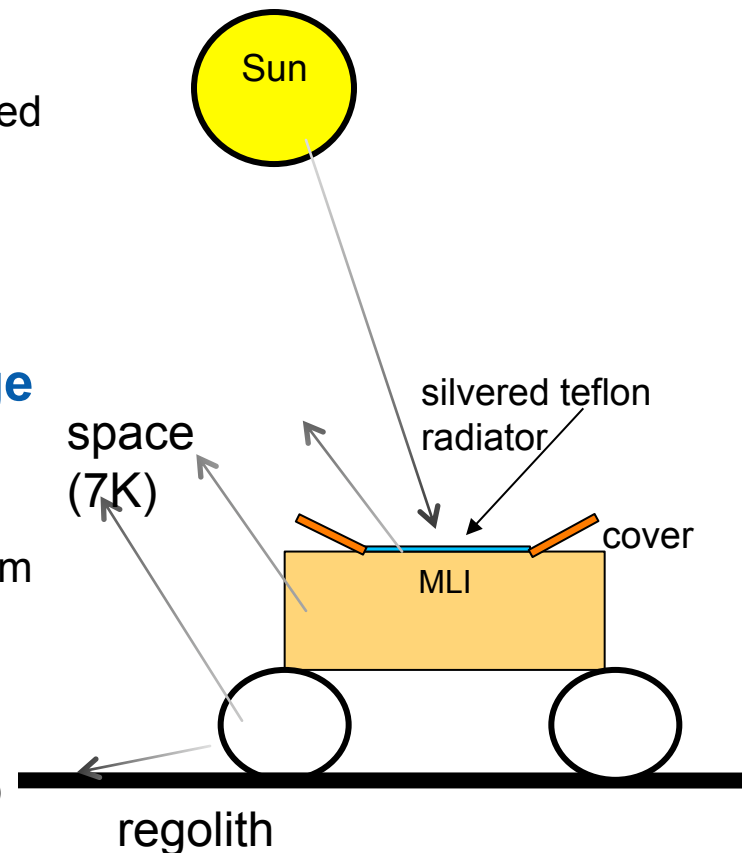
MER Tactical grade INS

- 12W, 750g

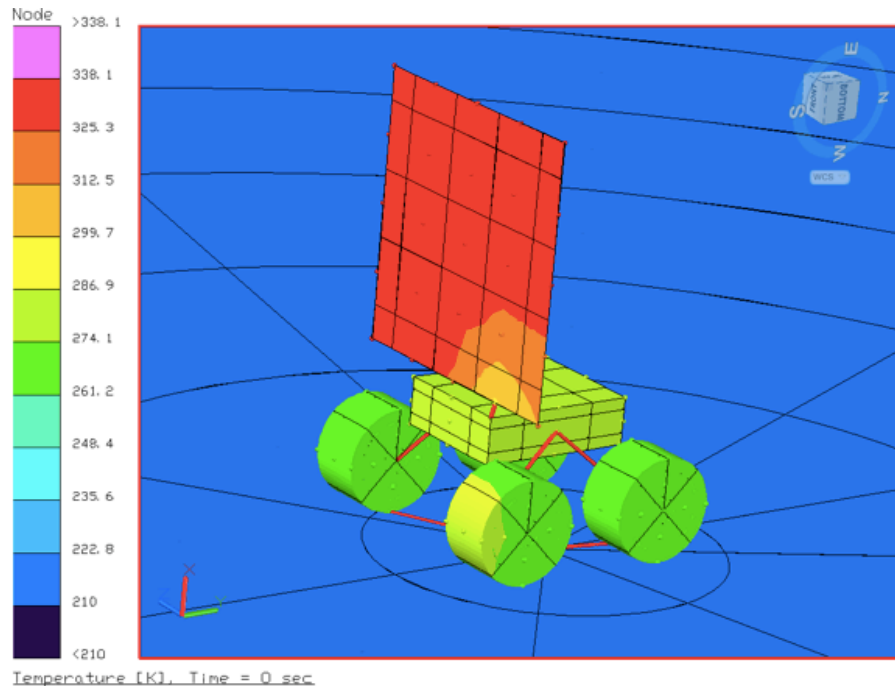


Thermal

- **Maintain systems within operating ranges**
 - Batteries 10 to 30C (-85 to 45C claimed for some Li-ion batteries)
 - Electronics -10 to 50C
 - Avoid repeated temperature changes
- **Thermal variation is challenge**
 - Dissipate power under max solar illumination
 - ... but retain heat during solar minimum
- **Lunar environment**
 - Heat radiation from regolith (radiated heat proportional to temperature difference⁴)
 - Variable radiator/sun geometry (equatorial)
 - Dust on radiative surfaces



Thermal



Thermal model developed in Thermal Desktop:

- Heat generated in the rover = 100 W
- Drive motors inside WEB
- Lunar regolith surface temperature = 210 - 250 K
 - Rover in sunlight (from side)
- Rover body covered in high emissivity and absorptivity material (Maxorb), no radiator required

Avoid hydrogen containing materials

- Interfere with neutron spectrometer
- Common phase change materials

Future Trades

- Use radiator if greater power needs
- In wheel hub motors

	Emissivity	Absorptivity	Temperature
Rover	0.88	0.88	282 - 292 K
Wheels	0.88	0.88	273 - 283 K
Solar panel (front/back)	0.83/0.76	0.81/0.27	335 - 342 K

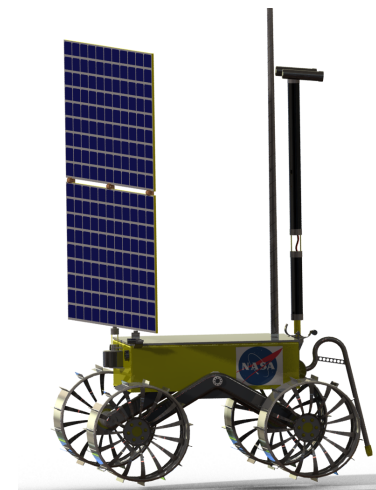
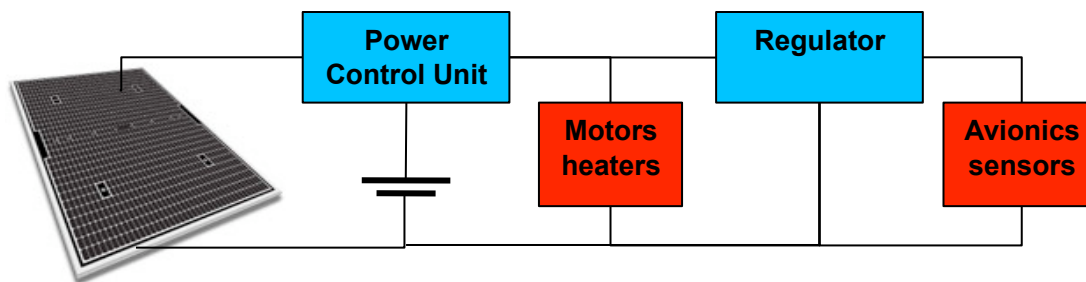


Power

Vertically mounted actuated solar panel

- Sized for max load (~100W) + losses (~20%) + 30% contingency
- Single DOF sufficient
- Single panel (~100 W/kg current operational SOA) + actuator lighter than 4 rigid body mounted panels.
- Compact packaging for launch.

Mass Budget (kg)		Margin	Total
Solar Panel	1.74	50%	2.62
Batteries	1.77	50%	2.65
Power control unit	3.49	0%	3.49
Voltage regulator	3.05	0%	3.05
Wiring	1.00	25%	1.25
Total	11.05	18%	13.06



Power: Solar Panels

100W/kg is commercial satellite
SOA

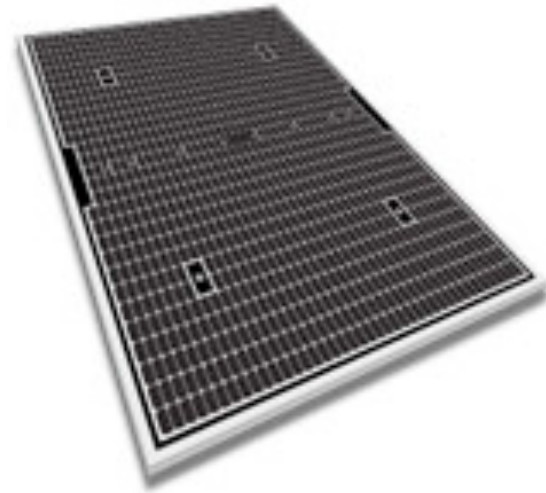
ISS 32 W/kg

Orion Ultra-flex 160 W/kg (very
large).

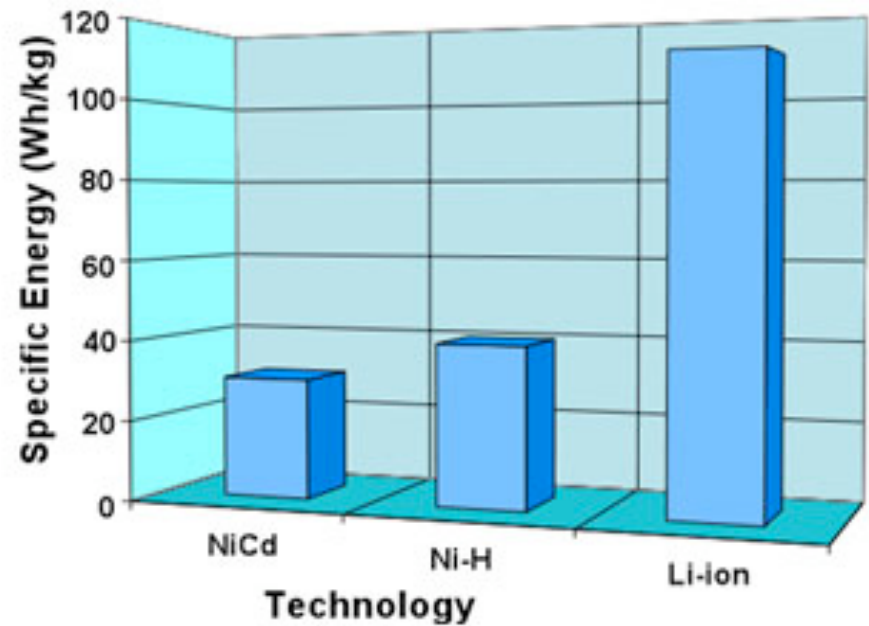
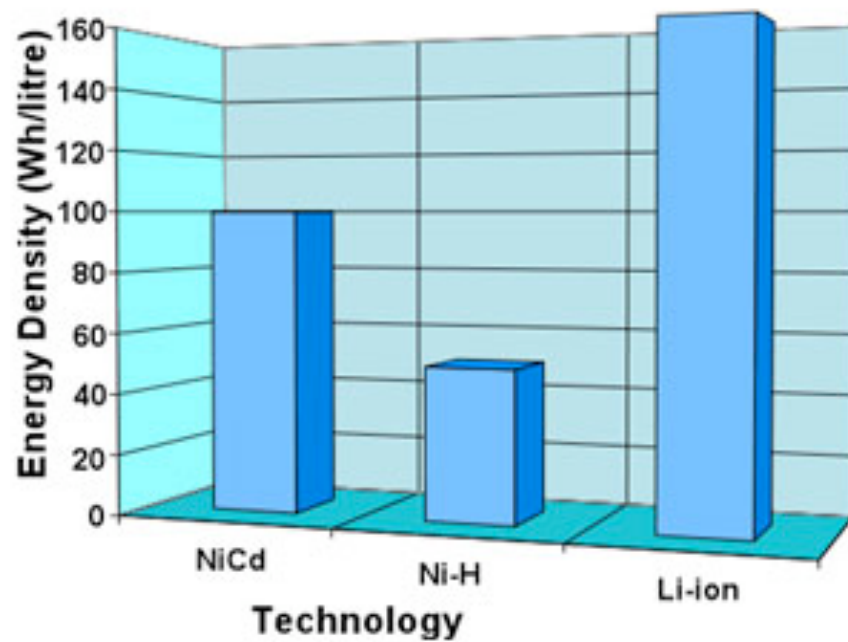
E.g.:

Emcore Triple Junction ZTJ
Space Solar Panel

- Average efficiency 29.5%
- low mass 84 mg/cm²
- radiation resistance with $P/P_o = 0.89$ @ 1-MeV, $5E14$ e/cm² fluence

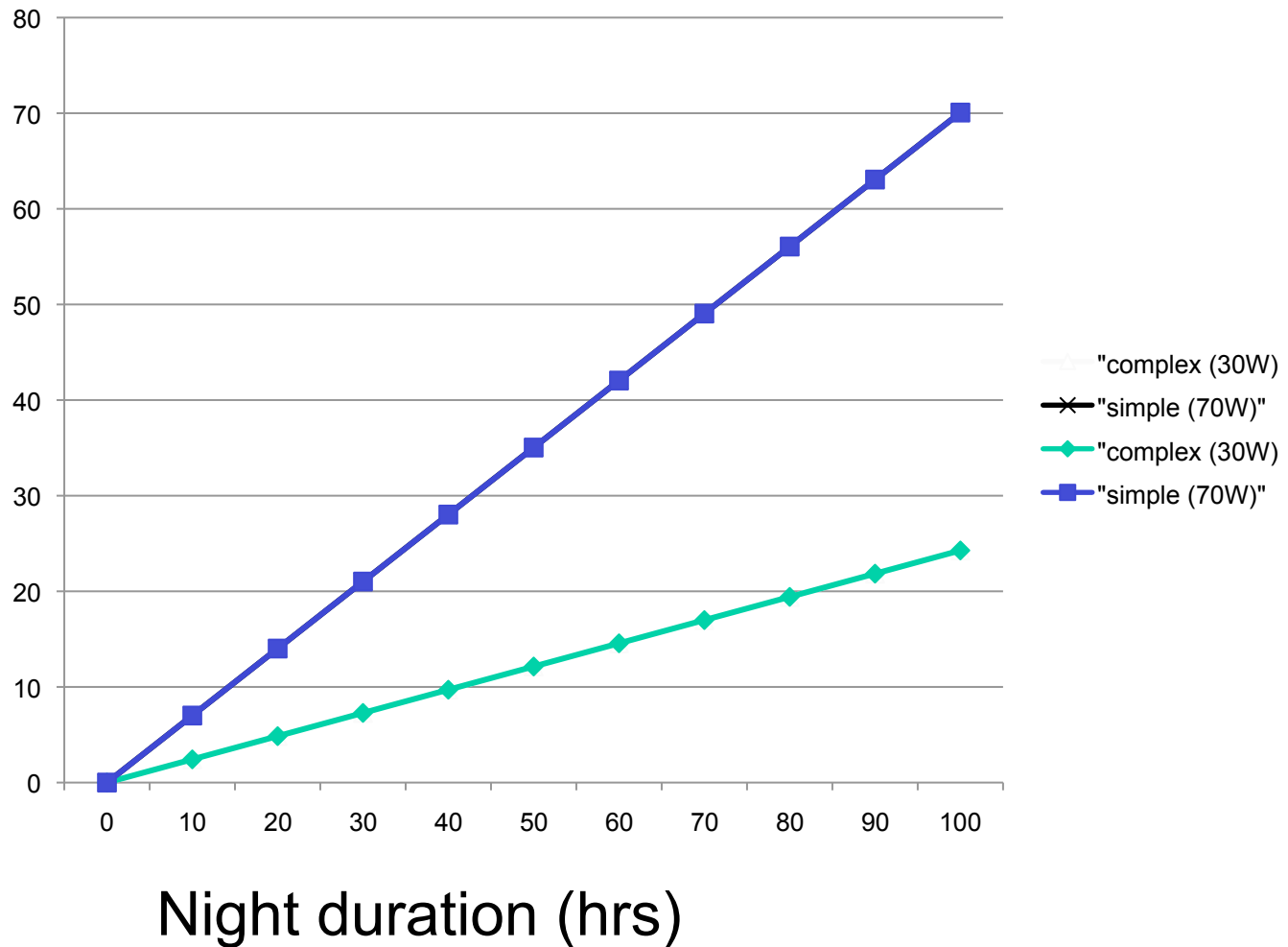


Power: Batteries



Power: Batteries for Night Time Survival

Li-Ion
battery
mass
110 W-hr/kg
100% discharge



Rover Size Trade

	1 kg (Nano-rover)	10kg (Packbot)	50-100kg (MER)
Navigation	--- 10cm look ahead cm obstacles 10m from lander (comms, navigation)	+- 1m look ahead 10cm obstacles 100m from lander (coms)	+++ 10m look ahead >10cm obstacles > 1km from lander
Cost	\$\$\$	\$\$	\$
Risk	Very High: shadows, cold traps, low thermal inertia, no battery, loss of comms	High: shadows, cold traps, loss of comms,	Medium: Thermal solutions exist Can accommodate flight h/w

